(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
26 April 2001 (26.04.2001)

PCT

(10) International Publication Number
WO 01/29574 A2

(51) International Patent Classification[7]: G01S 5/00

(21) International Application Number: PCT/US00/41412

(22) International Filing Date: 23 October 2000 (23.10.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/160,460 21 October 1999 (21.10.1999) US
60/181,848 11 February 2000 (11.02.2000) US

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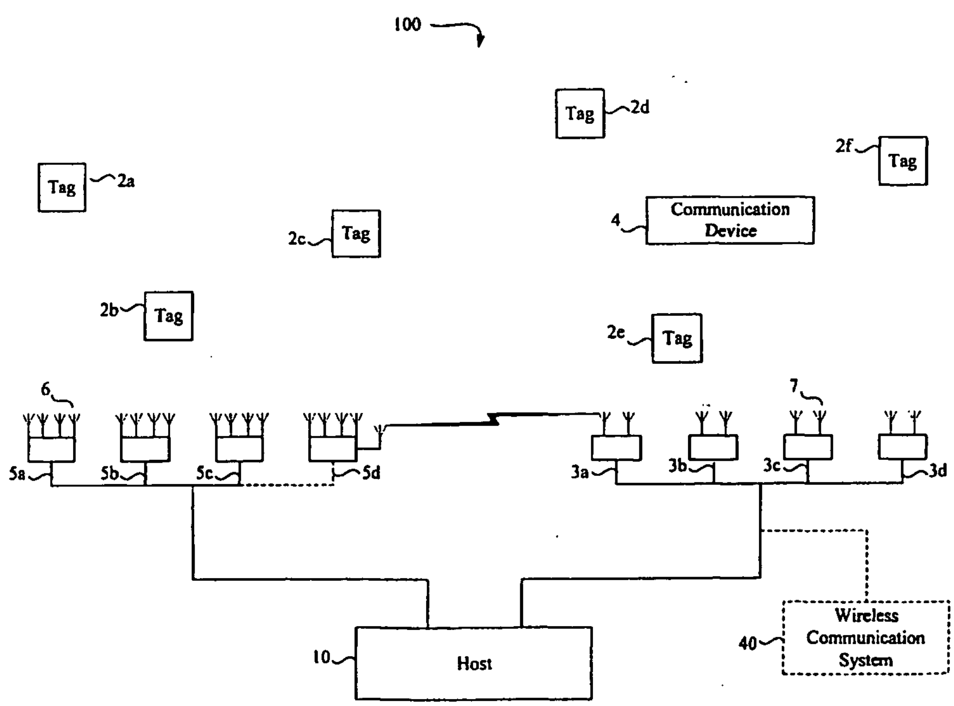
(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *Without international search report and to be republished upon receipt of that report.*

[Continued on next page]

(54) Title: METHOD AND APPARATUS FOR LOW COST ASSET LOCATION



(57) Abstract: A method and apparatus to communicate with tags in an asset location system using transmitter/receiver equipment that may be used to also transmit and receive wireless communications to and from devices other than tags, such as communication devices in a wireless Local Area Network (LAN).

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

METHOD AND APPARATUS FOR LOW COST ASSET LOCATION

RELATED APPLICATION

This application is related to and claims the benefit under 35 U.S.C. § 119(e) of U.S. provisional applications 60/160,460, filed October 21, 1999, and 60/181,848, filed February 11, 2000, which are hereby incorporated by reference in their entirety.

FIELD OF THE INVENTION

This invention relates to location identification of mobile and stationary assets.

BACKGROUND OF THE INVENTION

Monitoring and tracking the location of assets, such as personnel, inventory, vehicles, and so on, in a facility can be important, e.g., to ensure the safety, proper allocation, or appropriate use of the assets. One class of several different solutions that has been used to track assets is a Real Time Locating System (RTLS). This type of system usually includes a set of interrogator antenna modules arranged in an environment that can communicate over radio frequency bands with tags attached to assets that are to be tracked by the system. The tags and the antenna module transceivers communicate using radio frequency communication bands, and the information gathered from the tags is used by the system to generate useful data about the tagged assets, such as the location of the assets. Determining a location of the tags as used herein may indicate a general area in which a tag is located, a precise position of the tag (e.g., 2 or 3 dimensional coordinates of the tag relative to a reference point), a direction in which the tag is located relative to a reference direction or point, or any other suitable indication of the tag location.

Equipment for and installation of a dedicated asset location system infrastructure can in some cases be expensive, and when the total number of assets to be tracked is small, the cost per asset may be prohibitively high. In addition, a facility wishing to add an asset tracking resource to its operations may already have one or more wireless communication systems installed and operating within the facility. Thus, adding a separate wireless tracking system to the facility may be cumbersome, interfere with other communications, and/or require unwanted additional expense.

SUMMARY OF THE INVENTION

An illustrative embodiment of the invention provides a system for communication within an asset location system. In accordance with this embodiment, information is communicated to and from tagged objects and other devices. In particular, this embodiment of the present invention includes the use of transmitter/receiver equipment that may be used to transmit and receive information to and from tags, as well as to transmit and receive wireless communications to and from devices other than tags, such as communication devices in a wireless Local Area Network (LAN).

According to another embodiment of the present invention, a method for identifying a location of an asset includes transmitting a first wireless signal at a first frequency, receiving the first signal at an asset location, generating a second signal at a second frequency based on the first signal, transmitting the second signal as a wireless signal, converting the received second signal to the first frequency for reception by a receiver, and determining a location of the asset based on the converted second signal.

According to another embodiment of the present invention, a tag reader for use in determining asset location includes circuitry from an 802.11 transmitter that transmits a wireless signal, electronic circuitry that generates a converted signal at a first frequency from a received wireless signal at a second frequency, and circuitry from an 802.11 receiver that receives the converted signal from the electronic circuitry.

In another embodiment of the present invention, an access point for use in a wireless LAN includes a standard wireless LAN transmitter/receiver adapted to transmit signals to and receive signals from communication devices in a wireless LAN, and adapted to transmit signals to tags in an asset location system. The access point also includes electronic circuitry adapted to generate a converted signal at a first frequency from a wireless signal received from a tag at a second frequency, and circuitry from a standard wireless LAN receiver that receives the converted signal from the electronic circuitry.

According to still another embodiment of the present invention, an asset location system includes at least one tag, at least one wireless LAN access point, and a host adapted to determine a location of a tag based on communication between the tag and at least one wireless LAN access point.

According to still yet another embodiment of the present invention, an access point for use in a wireless LAN includes a first electronic device adapted to send and receive signals to and from communication devices in the wireless LAN and adapted to send signals to tags in an asset location system, and a second electronic device adapted to receive signals from the tags in the asset location system.

In accordance with still a further embodiment of the present invention, a method for communicating with communication devices in a wireless LAN and tags associated with assets in an asset location system includes sending and receiving wireless signals to and from communication devices in the wireless LAN from a first electronic device, sending wireless signals to tags in an asset location system from the first electronic device, and receiving signals from the tags at a second electronic device.

The following description and the appended drawings set forth in detail certain explicatory embodiments of the invention. However, these embodiments are indicative of but a few of the numerous ways in which various aspects of the invention may be employed. Other objects, advantages, and novel features of the invention will become evident from the following detailed description of the invention when considered in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Illustrative embodiments of the invention are described with reference to the following drawings, in which reference numbers indicate similar elements, and wherein:

Fig. 1 is a schematic block diagram of an illustrative asset location system according to one embodiment of the invention;

Fig. 2 is a schematic block diagram of an illustrative tag and tag reader for use with the asset location system of Fig. 1;

Fig. 3 is a schematic block diagram of an illustrative tag for use with the asset location system of Fig. 1; and

Fig. 4 is a more detailed schematic block diagram of an illustrative tag for use with the asset location system of Fig. 1.

DETAILED DESCRIPTION

An illustrative embodiment of the invention provides the ability to communicate with, and therefore locate, tags using transmitter/receiver equipment that may be used to

also transmit and receive wireless communications to and from devices other than tags, such as communication devices in a Wireless Local Area Network (WLAN). Thus, using various aspects of the invention, a facility having a pre-existing wireless communication system, such as a WLAN, may be modified to communicate with and enable location of tagged assets. The assets may be machinery, equipment, people, products in a warehouse, products being manufactured, vehicles, and/or any other mobile or stationary object. Since certain aspects of the invention may allow transmitter/receiver equipment to have a dual purpose of handling wireless communications with tags as well as other communication devices, a pre-existing WLAN may be modified to support an additional function of locating tagged assets without requiring installation of and investment in new infrastructure, such as antenna modules, associated cabling, conduit, etc., and thus substantial savings in time and expense may be realized.

In an illustrative embodiment of the invention, an asset location system includes a WLAN access point that can communicate with one or more tags as well as wirelessly communicate with devices within the WLAN. A host computer may communicate with the WLAN access point and determine tag location based on communication between the tags and the access point. The WLAN access point may operate using the 802.11 standard or any other suitable protocol for communicating wirelessly with devices in a network. In one embodiment, the access point may include a direct sequence 802.11 standard transmitter/receiver that transmits communication signals to tags in an asset location system as well as transmits and receives communication signals with respect to communication devices in the WLAN. The access point may include circuitry that converts signals received from the tags from one frequency to another frequency, and circuitry from an 802.11 receiver that demodulates the converted tag signals.

Thus, in this embodiment, a pre-existing WLAN access point that includes an 802.11 standard transmitter/receiver may be used to transmit signals to tags in the asset location system. The access point may be modified to include additional circuitry from an 802.11 receiver and other appropriate circuitry to convert, receive, and decode signals from the tags. Since 802.11 receivers plus associated circuitry to convert tag signals from one frequency to another frequency are relatively inexpensive compared to more sophisticated, but single-purpose, tag reading devices, the access point may be modified at relatively low expense to enable communication with tags.

In one illustrative embodiment of the invention, a first wireless signal may be transmitted at a first frequency to a tag. The tag may receive the transmitted signal at the first frequency and generate a second wireless signal at a second frequency, which is different from the first frequency, based on the first signal. The second wireless signal may be received from the tag at the second frequency and converted to the first frequency for demodulation and decoding by a receiver. This process may allow for the adaptation of highly integrated standard wireless communication equipment designed for use at the first frequency in systems other than tagged asset tracking to enable communication with standard asset tags. For example, WLAN access points typically include an 802.11 or other standard transmitter/receiver that both sends and receives signals with respect to devices in the LAN. As an example, an 802.11 transmitter/receiver typically sends and receives signals in the 2.4GHz band. One type of standard asset tag, such as the 3D-iD tag offered by PinPoint Corporation, receives signals in the 2.4GHz band and transponds the same signal frequency translated to the 5.8GHz band. Since standard 802.11 transmitter/receivers cannot directly receive signals in the 5.8GHz band, circuitry may be added to operate with a standard 802.11 receiver to convert the 5.8GHz signal from the tag to the 2.4GHz band, which is in the operating range of inexpensive 802.11 receiver chips. Once the transponded signal is demodulated and decoded by the 802.11 receiver, the signal can be relayed to, or otherwise used by, a host to determine a location of the tag.

In another illustrative embodiment of the invention, a tag reader may be constructed using standard radio transmitter/receiver devices, thereby potentially decreasing the cost of building a tag reader. Typical tag readers include specially designed transmitter/receiver circuitry and typically are relatively expensive, e.g., because the components used are not specifically designed to work together to modulate signals to and demodulate signals from the tag. In contrast, standard radio communication components, such as those designed for use in 802.11 transmitter/receivers, are widely used and are relatively inexpensive. By using one or more aspects of the invention, a tag reader may be built using standard radio transmitter/receiver devices along with other circuitry, potentially decreasing the cost of the tag reader. For example, a standard 802.11 transmitter may be used to transmit signals to tags in an asset location system. Signals sent back from standard asset tags may be at a different frequency than that sent by the 802.11 transmitter, and thus may not

be demodulated directly by an 802.11 receiver. Circuitry may be provided to operate with an 802.11 receiver to convert the received tag signal to an operating frequency that can be demodulated by the 802.11 receiver. Thus, a tag reader may be built from a standard 802.11 transmitter, an 802.11 receiver, and additional circuitry to convert a transponded tag signal to an 802.11 compatible signal.

Fig. 1 shows a schematic block diagram of an asset location system/WLAN 100 that may incorporate various aspects of the invention. Assets to be tracked may each be associated with tags 2. In this illustrative embodiment, six tags 2a-2f are shown, but it should be understood that more than six tags 2 may be used. In this illustrative embodiment, single function asset location tag readers 5 are used to cover one area (e.g., communicate with tags 2a-2c) and dual function access points 3 are used to cover another area (e.g., communicate with tags 2d-2f), but it should be understood that tag readers 5 and dual function access points 3 may be used separately or in combination within one area. The tags 2a-2c may communicate with the tag readers 5 so a host 10 may determine a location of the tags 2a-2c. The tags 2d-2f may communicate with dual function access points 3 so that a host 10 may determine the location of the tags 2d-2f based on the communications. The term tag reader is intended to refer to a device that can communicate with tags 2d-2f, but not necessarily with other wireless communication devices 4, such as PDAs, general purpose computers, and other devices, that may wirelessly communicate in a WLAN, such as a WLAN operating under the 802.11 standard. As used herein, the term access point refers to a device that can communicate with wireless communication devices 4 and that may also be configured to communicate with tags 2d-2f. When the system 100 includes access points 3, a wireless communication system 40 may control communications between devices 4 within the WLAN as is well known in the art and not described in detail here.

The system 100 may include only tag readers 5 or only access points 3, or a combination of tag readers 5 and access points 3. For example, the system 100 may have been a pre-existing WLAN that originally included standard LAN access points 3a-3d (devices that are not configured to communicate with tags 2) that were modified (such as with a plug-in module) to incorporate a tag communication capability. The system 100 may also be a system that includes only access points 3 that are configured in accordance with aspects of the invention and/or a system 100 that also includes tag readers 5 that

communicate with tags 2. (A system that uses high performance tag readers 5 either in addition to, or in combination with, one or more access points 3 in accordance with the invention is discussed in more detail below.)

In the illustrated embodiment, each tag reader 5 is associated with antenna modules 6. Each tag reader 5 may support one or more remote antenna modules 6, and/or a single antenna module co-located with the tag reader 5 module. It should also be noted that one or more tag readers, such as the tag reader 5d, may be mobile rather than fixed in place. A tag reader 5d may communicate with the host 10 through a network connection or through a WLAN access point 3. The host may include a programmed general purpose computer or network of computers and any other suitable components, such as storage devices, user interfaces, displays, software modules, hardware, communication devices, etc. to perform desired input/output and other functions.

Antenna structures and circuitry may be shared between the two functions of LAN communication and tag 2 location. For example, in the illustrated embodiment, each access point 3 is associated with antenna modules 7 that may serve the dual functions of communicating with wireless communication devices 4 and with tags 2d-2f. In an actual implementation, a given antenna module 7 may share the dual functions. The antenna modules 7 may be remote and/or co-located with respect to the access points 3.

Antenna modules 6 and 7 may be implemented in any suitable way. For example, in some cases, an antenna module 6 and 7 may include a single antenna structure. In the case of PinPoint's 3D-*i*D tag, for example, the antenna module includes multiple antenna structures, and some active components such as amplifiers and filters. In other products, such as WhereNet's Firefly system, antenna modules include a receiver and signal processing hardware. For the purpose herein, an antenna module may be a remote or integrated module that includes one or more antennas, in addition to supporting circuitry, if included.

The tag readers 5 or access points 3 may transmit signals to the tags at a first frequency, e.g., in compliance with the 802.11 standard. The tags 2 may be a standard type of tag 2 that receives a signal at a first frequency, such as a 2.4GHz signal received from a 802.11 transmitter that is part of a tag reader 5 or access point 3, converts the signal to a second frequency, such as a 5.8GHz signal, and transmits the converted signal

at the second frequency. The converted signal may be received at a tag reader 5 or access point 3 and converted back to the first frequency so that the signal may be demodulated and/or decoded by a standard radio receiver, such as an 802.11 receiver. Of course, a specially designed receiver could be designed to receive the transponded signal from the tag 2 at the second frequency, but such specially designed receivers may be relatively expensive. In contrast, standard radio receivers, such as 802.11 receivers, are widely used and mass manufactured. As a result, standard radio receivers may be much less expensive than a specially designed receiver. However, if the standard receiver is not capable of demodulating the transponded signal from the tag 2, circuitry may be added to operate with the standard receiver to convert the signal received from the tag 2 from the second frequency to the first frequency so that the standard receiver can demodulate the signal. This additional circuitry may be simple and relatively inexpensive, thus keeping the cost of modifying a standard radio receiver to receive tag signals lower. For example, this additional circuitry may include a VCO and mixer nearly identical to that in the tag 2, and thus available in ASIC form at very low cost. However, it should be understood that providing an ability to produce a low cost tag reader 5 and/or access point 3 is not at all essential to any of the aspects of the invention.

The tag reader 5 or access point 3 may be designed in a variety of different ways to use standard radio transmitter/receiver components. Fig. 2 shows a schematic block diagram of an illustrative embodiment of one such access point 3; the same principles may also be applied to a tag reader 5. In this embodiment, the access point 3 includes a transmitter 31, which may be a standard radio transmitter such as one designed for the 802.11 standard. The transmitter 31 may broadcast a first signal at a first frequency using an antenna module 34 to one or more tags 2, which transpond the signal or otherwise send back a signal that is at a second frequency. The signal may be received by a tag 2 using an antenna 21. The signal may pass through a mixer 25, where it may be mixed with the output of a VCO 26 at a suitable frequency which, when mixed with the first frequency produces the second frequency. The signal may then be retransmitted by the tag 2 using an antenna 29. The signal from the tag 2 may be received at an antenna module 34. Since the received signal at the antenna module 34 may be at a second frequency that can not be demodulated by a standard radio receiver 32 (such as one designed to support the 802.11 standard), a mixer or other suitable circuitry 33 may be provided to convert the received signal to the first frequency, which can be

demodulated by the standard radio receiver 32. The conversion may be accomplished using the output of a VCO 35.

Thus, a tag reader 5 or access point 3 may be constructed using a standard radio transmitter and receiver components, along with a mixer or other suitable circuitry, that is capable of communicating with standard tags 2, such as those that transpond an interrogation signal. The device may be made as a tag reader 5, i.e., a device that is suited mainly for communicating with tags 2, using standard radio communication devices, or may be made as a WLAN access point 3 that also has the capability to communicate with tags 2. For example, standard WLAN access points include a standard radio transmitter/receiver (such as the transmitter 31) that both transmits wireless signals to communication devices 4 in the WLAN and receives wireless signals from devices 4 in the WLAN. Thus, the transmitter 31 in the access point 3 may be a standard 802.11 device that both transmits and receives signals to and from the communication devices 4 in the WLAN, as well as transmit signals to tags 2. A standard access point 3 may be modified, e.g., by a plug-in device, to include the mixer or other circuitry 33 and the receiver 32 to enable reception of signals transmitted by the tags 2. As a result, standard access points in a WLAN that previously had no capability to receive signals from tags 2 may be modified, e.g., replaced or have additional circuitry added in a modular fashion, to enable tag signal reception. This may provide advantages since a WLAN may be initially installed using access points that are adapted to be relatively easily modified, e.g., by modular plug-in circuitry, so that in the future tag reading capability may be added to the system in a relatively simple way and at relatively low cost.

As an illustrative embodiment, the tags 2 in the system 100 may be PinPoint Local Positioning System (LPS) tags available from PinPoint Corporation. As designed, the PinPoint LPS tag receives energy centered at 2.44 GHz and re-transmits it centered at 5.80 GHz, phase or amplitude modulating an ID code onto the (uplink) response. 802.11 electronics, available as inexpensive chip sets from various vendors (such as Intersil's PRISM chipsets), used as the transmitter 31 may be capable of transmitting an FCC-compliant Direct Sequence signal centered at 2.44 GHz. The tag 2, without modification, may up-convert such a signal to the band centered at 5.80 GHz. At the tag reader 5 or access point 3, the 5.80 GHz signal may be down-converted to 2.44 GHz in the circuitry 33 by mixing with a 3.36GHz oscillator and filtering out all but the

difference product. The result is a time-delayed replica of the same signal that was transmitted by the 802.11 transmitter 31. This may be demodulated by chips designed for 802.11 receiver electronics in the receiver 32.

Phase modulated (uplink) PinPoint LPS tags 2 may be read by tracking the phase from the I/Q demodulator of the 802.11 chip in the receiver 32. On-off keyed (uplink) PinPoint LPS tags 2 may be detected by monitoring the output level from the 802.11 demodulator.

Location of the tags 2 may be determined using any suitable technique at the host 10, such as triangulation, received tag signal strength, and so on. As one example, a round trip time of flight of the signal sent from the access point 3 to the tag 2 and back may be estimated by correlating the received signal to determine the distance between the access point 3 and the tag 2, similarly to the technique used in the PinPoint LPS. Such tag location techniques are well known in the art and are not described in detail here. Since 802.11 communications run at an 11 MHz chip rate, instead of 40 MHz as in the PinPoint LPS, accuracy in determining tag location may be degraded. Similarly, since 802.11 devices use 11-chip sequences, instead of the 127-chip sequences used in the PinPoint LPS, performance may be correspondingly compromised.

As noted above, 802.11 chipsets, such as the PRISM chipsets commercially available from Intersil, may be used to transmit an FCC-compliant Direct Sequence signal centered at 2.44 GHz. Such a chipset provides a solution from the antenna modules 34 to a connection to another device, such as a network connection or computer bus (not shown) of the wireless communication system 40 for 11 Mbps WLAN systems. Using an 802.11 chipset such as a PRISM chipset may require that the position determining process operated by the host 10 be modified to accommodate an 11-chip sequence rather than, or in addition to, a 127-chip sequence, and to transmit at 11 Mbps instead of, or in addition to, 40 Mbps. Several different types of PRISM chipsets are available. One chipset that may be particularly useful with various aspects of the invention is the PRISM II chipset, which includes: a 2.4 GHz power amplifier, a 2.4 GHz RF/IF converter and synthesizer, an I/Q modulator/demodulator and synthesizer, a baseband processor with rake receiver, and a medium access controller. As use of such chips to read tags may involve modifications to the way those chips are utilized at a

protocol level, modification to the medium access controller and/or baseband processor may be involved in an implementation, particularly in the receiver 32.

When using an access point 3 that incorporates the dual functions of 802.11 communication and tag reading in a single device, operation of the access point 3 may have to be controlled to prevent interference between the two communications. To detect a PinPoint LPS tag 2 that is within range, the transmitter 31 in the access point 3 may emit a short pulse approximately every ½ millisecond (randomized), i.e., with an interval less than the length of the PinPoint LPS header. (The special purpose PinPoint LPS tag reader described in more detail below requires on the order of ¾ millisecond to cycle through all 16 antenna modules associated with a tag reader 5 while the header is being transmitted from the tag.) The pulse should be long enough for the 802.11 receiver 32 to detect a tag presence, approximately the length of one full sequence (plus system settling time), on the order of 1-5 microseconds. This pseudonoise sequence might be any sequence that may be sent in the normal course of 802.11 operation.

Once a tag 2 is found, the access point 3 may switch over to "ID detect mode" for the full length of the tag ID (currently approximately 2 milliseconds) to determine the identity of the tag 2. If the access point 3 happens to be transmitting 802.11 data anyway, the two functions may operate in tandem.

For an even simpler implementation of the access point 3 or tag reader 5, where on-off keyed (uplink) tags 2 exist in an environment without 5.8 GHz jammers, the receiver 32 may simply monitor received power at 5.80 GHz. In this embodiment, an access point 3 or tag reader 5 with interrogation pulses at 2.44 GHz may be built from literally any available parts designed for FCC-compliant emitters in the 2400-2483 MHz band. The PinPoint tag tends to filter signals toward the edges of the 2400-2483 GHz band, but sufficient signal is transponded across the band to support a frequency hopper emitter.

At the end of a tag datagram (described in more detail below), for example, the tag reader 5 or access point 3 may switch over to write mode, sending on/off keyed or other amplitude modulated (downlink) signals to the tag 2. Again, an 802.11 transmitter 31 may be used to send FCC-compliant RF energy in the 2.44 GHz band. This variation in energy may be detected in the tag 2 by monitoring variations in the incoming signal strength through the tag's Automatic Gain Control 41, as shown in Fig. 4. Manchester

encoding may be used for this purpose. Depending on possible interference from other RF equipment in the environment, such on/off keying may work well at substantial distances.

The tag reader 5 or access point 3 may be included in any of a wide range of devices used for bar code reading and/or wireless communication, such as PCMCIA cards, modular radios, base stations, and portable computing devices (battery operated and/or DC powered). This may decrease both the cost and the need for purchasing additional equipment that may accompany the installation of a full LPS.

To provide some additional context for the various aspects of the invention described above, an active radio frequency identification (RFID) system for asset location is described below with reference to Fig. 1. This system 100 may include specially-designed, single-purpose tag readers 5, in addition to, or in place of, the tag readers 5 and access points 3 described above. That is, in this illustrative embodiment, tag readers 5 may operate according to a high-performance mode (Option 1) or a lower-performance mode (Option 2) in compliance with the 802.11 or other similar standard. Thus, various aspects of this illustrative system may or may not incorporate the various illustrative embodiments of the asset location system 100 described above. In the description below, the term interrogator is intended to refer to either a tag reader 5 or an access point 3.

This section describes an active RFID system that supports at least the following system capabilities:

- Identify multiple tags in an area.
- Identify tags from long distances, typically in excess of 50 meters.
- Measure the distance of tags from tag reader antenna modules 6 and 7.

Use of multiple antenna modules 6 and 7 provides Local Positioning System (LPS) capabilities.

- 16-bit CRC packet-level protection may be applied to the return link (tag to reader) data.

In this typical RFID system, interrogators emit a direct sequence spread spectrum (DSSS) signal in the 2.45 GHz ISM band, and tags 2 respond by transponding that signal to the 5.8 GHz ISM band. The distance from the tag reader antenna modules 6 or 7 to the tag 2 may be estimated by round trip time of flight of the DSSS signal.

The RFID system is designed to track small, low-powered tags 2 that may be attached to assets and personnel in a facility. The tags 2 may be read at relatively long range, typically in excess of 50 meters. One or more antenna modules 6 or 7 may be typically installed in an area in a grid-like fashion to cover a complete facility. The antenna modules 6 or 7 may remain in continuous contact with tags 2 that are in range.

RFID systems of this type may be generally called "Local Positioning Systems" (LPS) or "Real Time Locating Systems" (RTLS). Both of these names emphasize the ability of the systems to cover a complete indoor space (as distinct from covering only portals), read tags 2 from long distances, and determine tag locations. The term LPS indicates that techniques similar to GPS (Global Positioning System) may be used to determine tag location.

In this illustrative embodiment, the system 100 includes a host 10 that itself may include one or a network of general-purpose computers and/or special purpose devices. The host 10 may include any suitable software modules, hardware, firmware, or other components necessary to perform desired input/output, analysis, reporting, communication or other functions. A multi-antenna module interrogator may send Direct Sequence Spread Spectrum interrogation signals at 2.4 GHz to tags 2 in range using the antenna modules 6 or 7. The tags 2 transpond these interrogation signals at low power to the 5.8 GHz band. Information from the interrogator may be sent to a computer that is part of the host 10 using a TCP/IP protocol, typically via an Ethernet connection. Software interfaces may be available on the host computer.

The asset location system 100 may incorporate one or more tag readers 5 or access points 3. In contrast to the system 100 described above, each tag reader 5 may operate according to a high-performance operation mode, i.e., Option 1 described below. In addition, each tag reader 5 or access point 3 may operate according to another operation mode, i.e., Option 2 described below. Option 1 is a high-performance implementation, intended to read tags at maximum range and with highest location accuracy and is typically used with tag reader 5/antenna module 6 configurations. Option 1 utilizes 127 chip sequences at a rate of 40 megachips per second. Forty megachips per second is the maximum rate supported by the 2400-2483 MHz band. Option 2 is intended for lower performance at lower cost, utilizing an 11-chip sequence at a rate of 11 megachips per second, e.g., in compliance with the 802.11 standard. Thus,

Option 2 signal characteristics are identical to those specified for the 802.11 networking protocol. The specifications for both Options are described in detail in Tables 2 and 3 below.

More specifically, interrogators may emit a direct sequence spread spectrum interrogation signal in the 2400-2483.5 MHz ("2.45 GHz") band. Tags 2 in range of an antenna module 6 or 7 up-convert the center frequency of the interrogation signal from 2442 MHz to 5800 MHz and filter the result to ensure that emissions are limited to the 5725-5875 MHz ("5.80 GHz") band. Tag ID information may be modulated onto the return signal, which may be transmitted back to the interrogator at low power. The interrogator extracts the Tag ID from this return signal and determines the distance of the tag 2 from the antenna module 6 by measuring the round trip time of flight of the DSSS signal. Both the interrogator and the tag comply with FCC Part 15 regulations, so no license may be needed for operation.

In a multi-antenna module configuration, an interrogator may quickly cycle among its antenna modules 6 or 7, determining the distance between all of its antenna modules 6 or 7 and a given tag 2. Once the distance to three antenna modules 6 or 7 is found, the location of the tag 2 in space may be estimated. In many situations, it may be possible to get a good estimate of tag location from fewer than three antenna modules 6 or 7. For example, a grocery store aisle may be covered by two antenna modules 6 or 7, one at each end, and most hallways may be similarly covered.

The tags 2 operate according to a "tag-talks-first" paradigm. Tags 2 wake up spontaneously, transmit their unique codes, and then go back to sleep. Each transmission may be short, on the order of 2.5 milliseconds. The sleep time may vary based on application requirements. For example, tags 2 attached to personnel might transmit every two seconds, while tags 2 attached to inventory might be set to transmit once per minute.

The tag data protocol may include a capability to pass along information provided by a closely integrated device. For example, a specialized tag 2 integrated with a temperature sensor may be used to report current and historical environmental data. As another example, personnel tags 2 generally include a "call button." To support such low-bandwidth communication, the tag data protocol may include bandwidth to uplink a small amount of status information.

Fig. 3 shows a schematic block diagram of an illustrative embodiment of a tag 2. The tag 2 receives a DSSS signal from the antenna module 6 or 7 or tag reader 5/access point 3 at a receive antenna 21 centered at 2442 MHz or another frequency in the 2400-2483 MHz band. This signal may be filtered by a filter 22, amplified by an amplifier 23, and modulated by a modulator 24. The modulator 24 may pass the signal unchanged or invert the phase of the signal by 180°. The modulator 24 may operate under microprocessor (not shown) control. The signal may then be mixed at a mixer 25 with the output of a 3358 MHz oscillator (VCO 26), resulting in a signal of 2.442+3.358=5.800 GHz. This 5.8 GHz response may then be amplified by an amplifier 27, filtered by a filter 28, and transmitted though a transmit antenna 29. Fig. 4 shows a more detailed schematic block diagram of an illustrative embodiment of a tag 2.

Note that the DSSS signal may not be demodulated by the tag 2, but simply passed through. This provides the system with the performance of a DSSS system without the necessity of a DSSS modulator or demodulator on the tag 2. In enhanced implementations, an Rx Threshold Detector may be added to the receiver 42, providing support for an on-off keyed forward link or other AM modulated link. The implementation of such a forward link is not included in this description, as it may vary according to application requirements.

Fig. 3 is intended to clarify possible aspects of the transponding and modulation operations that may occur in the tag 2. No implementation recommendation or constraint is intended with regard to nature and placement of components.

The tag 2 shown in Fig. 3 performs two basic functions:

1. It provides an RF mirror (frequency translation) so the host 10 can locate it.

2. It modulates the received signal to transmit the tag information back to the host 10 via the access point 3 or tag reader 5.

The tag 2 spends most of its time in the sleep state. During its active interval, the tag 2 "wakes up" by stabilizing its internal oscillators, calculating a CRC, initiating radio transmission and modulation, sending its datagram, and finally returning to the sleep state.

As shown in Table 1, the tag datagram may include eleven contiguous sections. The sections include the tag preamble, the end preamble (optional), the start data

sequence, the datagram version identifier, the manufacturer tag ID LSB, the tag serial number, the status bits, the tag data, the manufacturer tag ID MSB, the CRC and end bit. This datagram may be sent once during the tag RF-on cycle. Each individual bit spans a 19.05-microsecond period, corresponding to an Option 1 interrogator signal of six 127-chip sequences at a rate of 40 megachips per second.

TABLE 1. TAG DATAGRAM.

Tag preamble	End preamble	Start data	Version	MfrTag ID LSB	Tag serial number	Status	Tag data	MfrTag ID MSB	CRC	End bit repeat of last checksum bit

- The ***tag preamble*** may be used by the interrogator to perform three functions:

1. To search for the tag 2 sequentially through each of the antenna modules 6 or 7. If a tag 2 is seen in this search process, the interrogator may then proceed with the subsequent steps;

2. To determine the distance to the tag 2 from each antenna module 6 or 7 that sees the tag 2;

3. To pick the best antenna module 6 or 7 for collecting the rest of the datagram.

The tag preamble may include a constant bit pattern of 38 effective one bits. A one bit is defined as having no phase change, so the preamble has a constant phase. The preamble includes 31 bits for determination of distances from each of up to 16 antenna modules 6 or 7, and 7 bits to allow for interrogator overhead. If fewer than 16 antenna modules 6 or 7 are connected and/or supported, the interrogator may reduce its duty cycle accordingly with minimal impact on performance.

- The ***end preamble*** may allow the interrogator to synchronize its baseband clock. The end preamble begins by the tag 2 shutting down its transmitter for six microseconds. The rest of the first bit interval, and the remaining three bits allows the interrogator to reacquire the tag signal. This field is optional, and improves reliability in certain interrogator designs.

- The ***start data sequence flag*** consists of a "010" bit pattern to indicate end-of-preamble.

- The ***tag version field*** follows the start data sequence. It includes 4 bits that may be used to support future enhancements to the protocol and to provide a signal for future interrogators to enable backward compatibility. In the current version of the protocol, its value is always "0000".

- The ***MfrTagID*** (Manufacturer Tag ID) ***LSB*** includes 8 bits (one byte) that represent the second half of the MfrTagID.

- The ***tag serial number*** follows the tag version. It includes 24 bits organized as three bytes (msb). There is no special meaning to the three bytes other than the tag serial number.

- The ***tag status*** or ***housekeeping field*** follows the tag identification. It includes 8 bits that may be used for fixed housekeeping purposes. The eight bits are UUUUUUTB (msb), where B=1 indicates low battery and T=1 is a tamper indicator. For personnel tags, the tamper detect bit is used to indicate use of a call button. The six remaining bits are left unspecified, and are intended for application-specific uses.

- The ***tag data field*** follows the status field. This section includes 16 bits whose function may vary by application. A typical application is to report the status of an environmental sensor, or to report status information from tagged equipment.

- The ***MfrTagID MSB*** includes 8 bits (one byte) that represent the first half of the MfrTagID.

- The next to last field is a ***CRC***. The CRC takes as input (in order) the version, MfgTagID LSB, Tag serial number, Status, Tag data, and MfrTagID MSB fields. The CRC is similar to the CCITT CRC, with some differences in settings, and is defined as follows:

Length	Polynomial	Direction	Initial Value
16 bits	0x1021	MSB→LSB	0x0000

- The final field is used as a ***stop bit***. It is a replication of the last bit in the checksum field and allows for a smooth and controlled end of acquisition within the

interrogator and graceful tag shutdown. It is also possible for enhanced tags 2 to receive OOK messages from the interrogator immediately following the end of the datagram, for purposes such as acknowledgements, changes in tag parameters (such as sleep times), or commands to devices attached to the tags 2.

Each bit of the tag datagram may last for 19.05 microseconds and there may be effectively 126 bits in a datagram (excluding the optional end preamble), so the datagram lasts for about 2.4 milliseconds.

At the end of a tag transmission, the tag 2 may go to sleep for an amount of time pre-programmed into its microprocessor. A typical three-second sleep time provides about a 1000:1 duty cycle. It may be desirable to include a randomized component in the sleep cycle to prevent pairs of tags 2 from transmitting in a repeated synchronized fashion. The randomization function is not specified herein, as it may vary according to the implementation of the sleep cycle. A randomization formula that varies as a function of tag ID is recommended. Although the system may work well with a small number of frequently transmitting tags, the minimum sleep time recommended in the current system is 1.0 seconds. This is an average, accounting for randomization.

While the invention has been described with reference to various illustrative embodiments, the invention is not limited to the embodiments described. Thus, it is evident that many alternatives, modifications, and variations of the embodiments described will be apparent to those skilled in the art. Accordingly, embodiments of the invention as set forth herein are intended to be illustrative, not limiting. Various changes may be made without departing from the invention.

TABLE 2. FORWARD LINK PARAMETERS

Parameter Number	**Parameter Name**	**Description**
F 1	Operating Frequency Range	2400-2483.5 MHz
F 1a	Default Operating Frequency	2442 MHz (center frequency)
F 1b	Operating Channels	Option 1: 2442 MHz only (Center Frequency) Option 2: 11 channels from 2412 to 2462 in 5 MHz increments (center frequency)
F 1c	Operating Frequency Accuracy	± 25 ppm maximum.
F 1d	Frequency Hop Rate	Not applicable
F 1e	Frequency Hop Sequence	Not applicable
F 2	Occupied Channel Bandwidth	Option 1: The 20 dB bandwidth is regulated by FCC Part 15, Section 15.247 Option 2: The transmitted spectral products shall be less than –30 dBr (dB relative to the SINx/x peak) for fc – 22 MHz < f < fc –11 MHz, fc +11 MHz < f < fc + 22 MHz, –50 dBr for f < fc –22 MHz, and f > fc + 22 MHz, where fc is the center channel frequency.
F 3	Interrogator Transmit Maximum EIRP	The maximum EIRP transmitted by the interrogator antenna is regulated by FCC Part 15, Section 15.247. At the time of drafting of this document, this maximum is 30 dBm output from the interrogator and 36 dBm EIRP from the interrogator transmit antenna.
F 4a	Interrogator Transmit Spurious Emissions, In-Band	Option 1: Not applicable. Option 2: See F2.
F 4b	Interrogator Transmit Spurious Emissions, Out-of-Band	The interrogator shall transmit in conformance with spurious emissions requirements defined in reference 2.1.2, sections 15.205 and 15.209.
F 5	Interrogator Transmitter Spectrum Mask	The interrogator transmitter spectrum mask is regulated by FCC Part 15, Section 15.247. At the time of drafting of this document, the peak power spectral density conducted from the intentional radiator to the antenna shall not be greater than 8 dBm in any 3 kHz band during any time interval of continuous transmission.

Parameter Number	**Parameter Name**	**Description**
F 5a	Transmit to Receive Turn Around Time	Not applicable.
F 5b	Receive to Transmit Turn Around Time	Not applicable.
F 5c	Interrogator Transmit Power On Ramp	Not applicable.
F 5d	Interrogator Transmit Power Down Ramp	Not applicable.
F 6	Modulation	DSSS Option 1: MPSK (BPSK or higher) Option 2: DBPSK, DQPSK, CCK
F 6a	Spreading Sequence	Option 1: Implementation-specific combination of the following 127-chip sequences: 03,FA,A6,77,4B,1B,DA,D9,23,85,F2,B9,A2,78,A1,83 02,4D,3D,C3,F8,EC,52,FA,A1,6F,39,59,83,6B,A3,23 03,36,39,D7,09,82,AD,25,3C,8D,43,FB,B7,A2,CB,E3 02,C1,D0,9C,69,2E,DC,D9,5A,FB,C3,11,4C,F5,47,F3 03,09,3F,BE,3A,A5,7A,67,35,88,BB,21,E5,B8,28,DB 03,A8,B8,F7,6B,FA,61,A1,4B,65,58,82,7C,E4,8C,DF 02,86,C8,3C,5A,C2,27,7A,33,4C,72,AE,A4,BF,9F,6F 02,B7,F3,6A,89,33,C7,75,E9,65,39,18,B8,43,41,F7 03,5D,2A,DC,84,49,EA,0B,CE,FE,CB,19,B4,7C,38,A7 Option 2 (DBPSK and DQPSK): 10110111000 Option 2 (CCK): As per 802.11b
F 6b	Chip Rate	Option 1: 40 megachips/sec Option 2: 11 megachips/sec
F 6c	Chip Rate Accuracy	Option 1: Not critical. Option 2: ± 25 ppm maximum
F 6d	On-Off Ratio	Not applicable.
F 6e	Duty Cycle	Not applicable
F 6f	FM Deviation	Not applicable.
F 7	Data Coding	Not applicable (read-only)
F 8	Bit Rate	Option 1: 315 KBPS Option 2: 1, 2, 5.5, or 11 mbps

Parameter Number	**Parameter Name**	**Description**
F 8a	Bit Rate Accuracy	Option 1: Not critical. Option 2: ±25 ppm maximum
F 9	Interrogator Transmit Modulation Accuracy	Not restricted.
F 10	Tag Receiver Non-Destructive Input RF Level	Tag must be able to withstand power delivered from a 1000 mW interrogator at 0.5 meters, or from a 100-mW interrogator at any distance.
F 11	Preamble	Not applicable.
F 11a	Bit Sync Sequence	Not applicable.
F 11b	Frame Sync Sequence	Not applicable.
F 12	Scrambling	Not applicable.
F 13	Bit Transmission Order	Not applicable

TABLE 3. RETURN LINK PARAMETERS

Parameter Number	Parameter Name	Description
R 1	Operating Frequency Range	5725-5875 MHz
R 1a	Default Operating Frequency	5800 MHz (center)
R 1b	Operating Channels	Frequency shifting transponder: 2400-2484 to 5758-5842
R 1c	Operating Frequency Accuracy	Up-conversion accomplished using 3358 MHz oscillator, ±35 ppm.
R 1d	Frequency Hop Rate	Not applicable.
R 1e	Frequency Hop Sequence	Not applicable.
R 2	Occupied Channel Bandwidth	Up-converted and low power approximate replica of 2400-2484 spectrum. Matches Interrogator spectral profile in normal operation.
R 3	Transmit Maximum EIRP	The maximum EIRP transmitted by the tag antenna is regulated by FCC Part 15, Section 15.249. At the time of drafting of this document, this maximum is 50 millivolts/meter measured at a distance of 3 meters. Field strength limits are based on average limits. However, the peak field strength of any emission shall not exceed the maximum permitted average limits by more than 20 dB under any condition of modulation.
R 4a	Transmit Spurious Emissions, In-Band	Not applicable.
R 4b	Transmit Spurious Emissions, Out-of-Band	The tag shall transmit in conformance with spurious emissions requirements defined in FCC Part 15, Section 15.249. At the time of drafting of this document, emissions radiated outside of the 5725-5875 MHz frequency band, except for harmonics, shall be attenuated by at least 50 dB below the level of the fundamental or to the general radiated emission limits in §15.209, whichever is the lesser attenuation. Harmonics are limited to 500 microvolts/meter.

Parameter Number	Parameter Name	Description
R5	Transmit Spectrum Mask	Transponder; not applicable.
R 5a	Transmit to Receive Turn Around Time	Not applicable.
R 5b	Receive to Transmit Turn Around Time	Not applicable.
R 5c	Transmit Power On Ramp	Radio shall be disabled until power on ramp completed.
R 5d	Transmit Power Down Ramp	Radio shall be disabled prior to power down ramp.
R 6	Modulation	DBPSK.
R 6a	Sub-carrier Frequency	Not applicable.
R 6b	Sub-carrier Frequency Accuracy	Not applicable.
R 6c	Sub-Carrier Modulation	Not applicable
R 7	Data Coding	Phase change of 0 represents 1; phase change of π represents 0.
R 7a	Spreading Sequence	Not applicable; transponder.
R 7b	Chip Rate	Not applicable; transponder.
R 7c	Chip Rate Accuracy	Not applicable; transponder.
R 6d	On-Off Ratio	Not applicable.
R 6e	Duty Cycle	Not applicable.
R 6f	FM Deviation	Not applicable.
R 8	Bit Rate	1 bit per 19.05 microseconds.
R 8a	Bit Rate Accuracy	±10,000 ppm
R 9	Tag Transmit Modulation Accuracy	10°
R 11	Preamble	Not applicable.
R 11a	Bit Sync Sequence	Not applicable.
R 11b	Frame Sync Sequence	Not applicable.
R 12	Scrambling	None.
R 13	Bit Transmission Order	MSB

CLAIMS

1. A method for identifying a location of an asset, comprising:

transmitting a first wireless signal at a first frequency;

receiving the first signal at an asset location;

generating a second signal at a second frequency based on the first signal;

transmitting the second signal as a wireless signal;

converting the received second signal to the first frequency for reception by a receiver; and

determining a location of the asset based on the converted second signal.

2. The method of claim 1, wherein the step of transmitting a first wireless signal comprises:

transmitting a signal using an 802.11 wireless LAN transmitter.

3. The method of claim 1, wherein the step of transmitting a first wireless signal comprises:

transmitting a direct sequence spread spectrum signal in the 2.45GHz band.

4. The method of claim 1, wherein the step of transmitting a first wireless signal comprises:

transmitting the first wireless signal using a device adapted to transmit communication signals to communication devices in a wireless LAN.

5. The method of claim 1, wherein the step of receiving the first signal at an asset location comprises:

receiving the first signal at a tag associated with the asset.

6. The method of claim 1, wherein the step of generating a second signal at a second frequency comprises:

transponding the first signal at the second frequency.

7. The method of claim 1, wherein the step of converting the received second signal to the first frequency comprises:

mixing the received second signal with another signal.

8. The method of claim 1, wherein the step of converting the received second signal to the first frequency comprises:

mixing the received second signal with the output of an oscillator.

9. The method of claim 1, further comprising:

receiving the converted signal at an 802.11 wireless LAN receiver.

10. The method of claim 1, wherein the step of determining a location of the asset comprises:

determining a location of a tag that sent the second signal based on a distance of the tag from location where the second signal was received.

11. The method of claim 1, wherein the step of determining a location of the asset comprises:

determining a round trip time of flight between a time when the first signal is transmitted and a time when the second signal is received.

12. The method of claim 1, wherein the step of determining a location of the asset comprises:

determining a distance between a tag that sent the second signal and a location where the second signal was received.

13. A tag reader for use in determining asset location, comprising:

circuitry from an 802.11 transmitter that transmits a wireless signal;

electronic circuitry that generates a converted signal at a first frequency from a wireless signal at a second frequency; and

circuitry from an 802.11 receiver that receives the converted signal from the electronic circuitry.

14. The tag reader of claim 13, wherein the electronic circuitry comprises:
an oscillator; and
a mixer.

15. An asset location system comprising the tag reader of claim 13.

16. An access point for use in a wireless LAN, comprising:

a standard wireless LAN transmitter/receiver adapted to transmit signals to and receive signals from communication devices in a wireless LAN, and adapted to transmit signals to tags in an asset location system;

electronic circuitry adapted to generate a converted signal at a first frequency from a wireless signal received from a tag at a second frequency; and

circuitry from a standard wireless LAN receiver that receives the converted signal from the electronic circuitry.

17. The access point of claim 16, wherein the electronic circuitry comprises:
an oscillator; and
a mixer.

18. An asset location system comprising the access point of claim 16.

19. A wireless LAN comprising the access point of claim 16.

20. An asset location system comprising:
at least one tag;
at least one wireless LAN access point; and
a host adapted to determine a location of a tag based on communication between the tag and at least one wireless LAN access point.

21. The asset location system of claim 20, wherein the wireless LAN access point comprises:

a standard wireless LAN transmitter/receiver adapted to transmit signals to and receive signals from communication devices in a wireless LAN, and adapted to transmit signals to tags;

electronic circuitry adapted to generate a converted signal at a first frequency from a wireless signal received from a tag at a second frequency; and

a standard wireless LAN receiver that receives the converted signal from the electronic circuitry.

22. The system of claim 21, wherein the standard wireless LAN transmitter/receiver is an 802.11 transmitter/receiver and the standard wireless LAN receiver is an 802.11 receiver.

23. The system of claim 21, wherein the electronic circuitry comprises:

an oscillator; and

a mixer.

24. An access point for use in a wireless LAN comprising:

a first electronic device adapted to send and receive signals to and from communication devices in the wireless LAN and adapted to send signals to tags in an asset location system; and

a second electronic device adapted to receive signals from the tags in the asset location system.

25. A method for communicating with communication devices in a wireless LAN and tags associated with assets in an asset location system, comprising:

sending and receiving wireless signals to and from communication devices in the wireless LAN from a first electronic device;

sending wireless signals to tags in an asset location system from the first electronic device; and

receiving signals from the tags at a second electronic device.

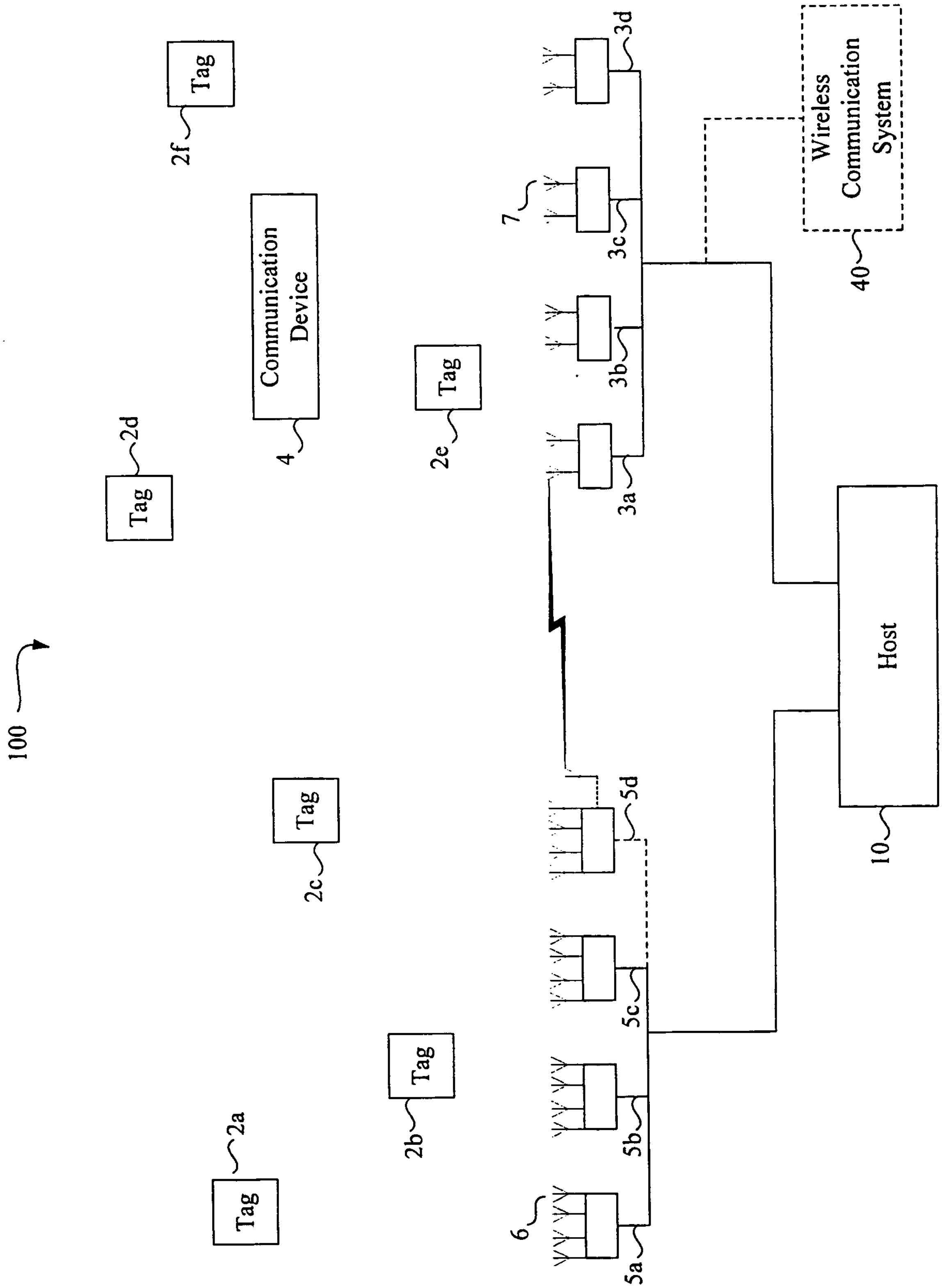
100
Tag
2f
Communication Device
4
Tag
2e
Tag
2d
Tag
2c
Tag
2b
Tag
2a
3d
7
3c
3b
3a
Wireless Communication System
40
Host
10
5d
5c
5b
5a
6

Fig. 1

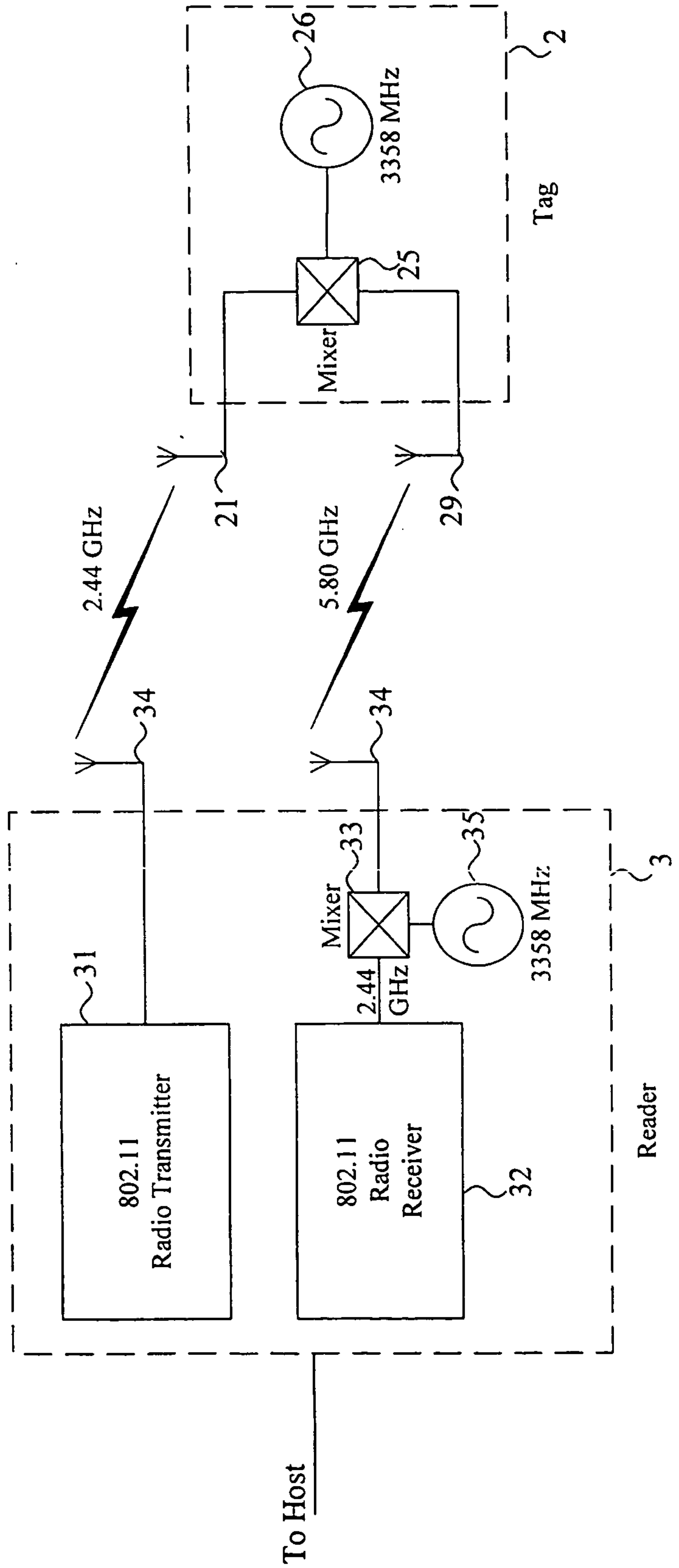
Tag
2
26
3358 MHz
Mixer
25
21
29
2.44 GHz
5.80 GHz
34
34
Reader
3
31
802.11
Radio Transmitter
802.11
Radio
Receiver
32
Mixer
33
35
3358 MHz
2.44
GHz
To Host

Fig. 2

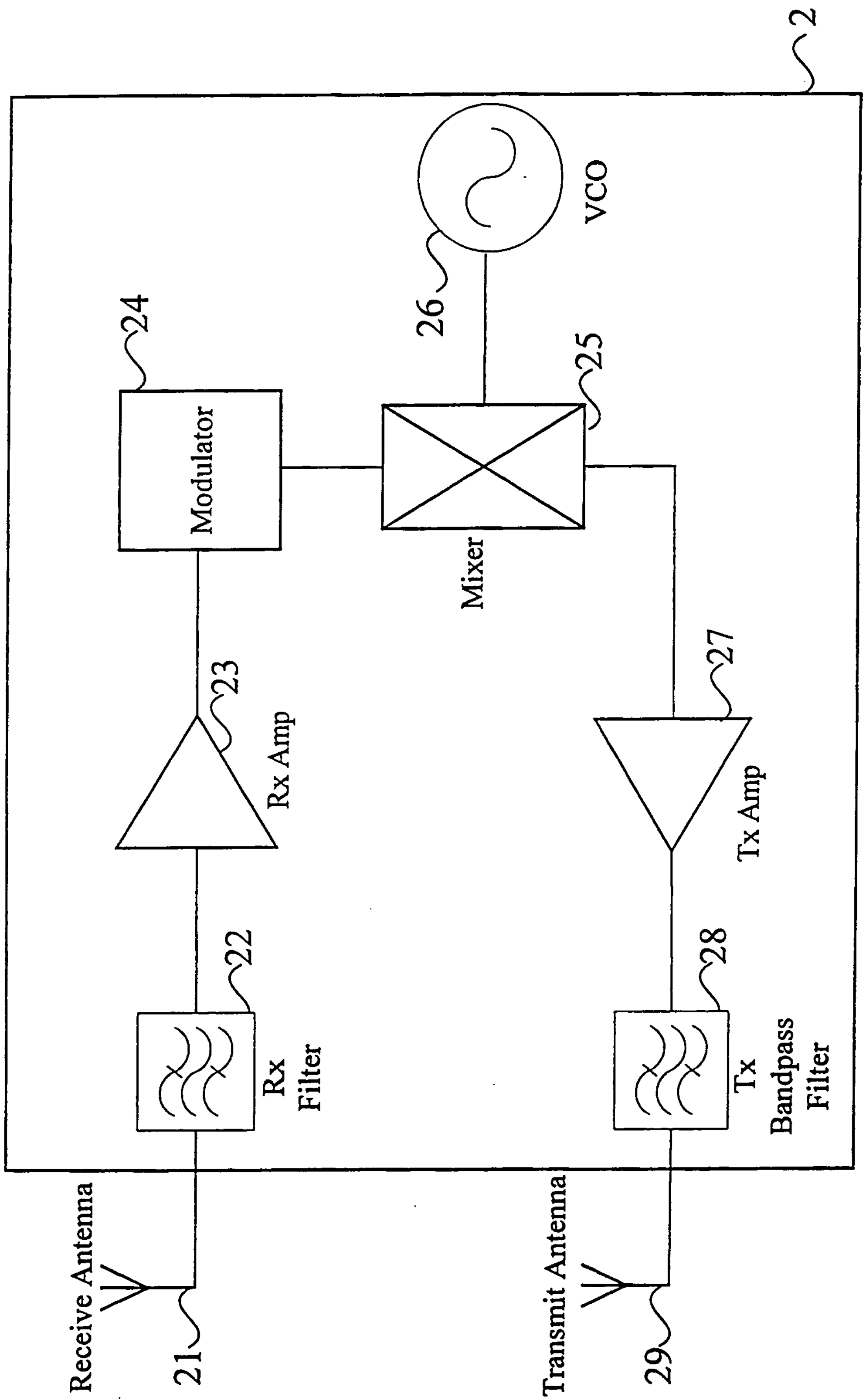
2
Modulator
24
VCO
26
Mixer
25
Rx Amp
23
Tx Amp
27
Rx
Filter
22
Tx
Bandpass
Filter
28
Receive Antenna
21
Transmit Antenna
29

Fig. 3

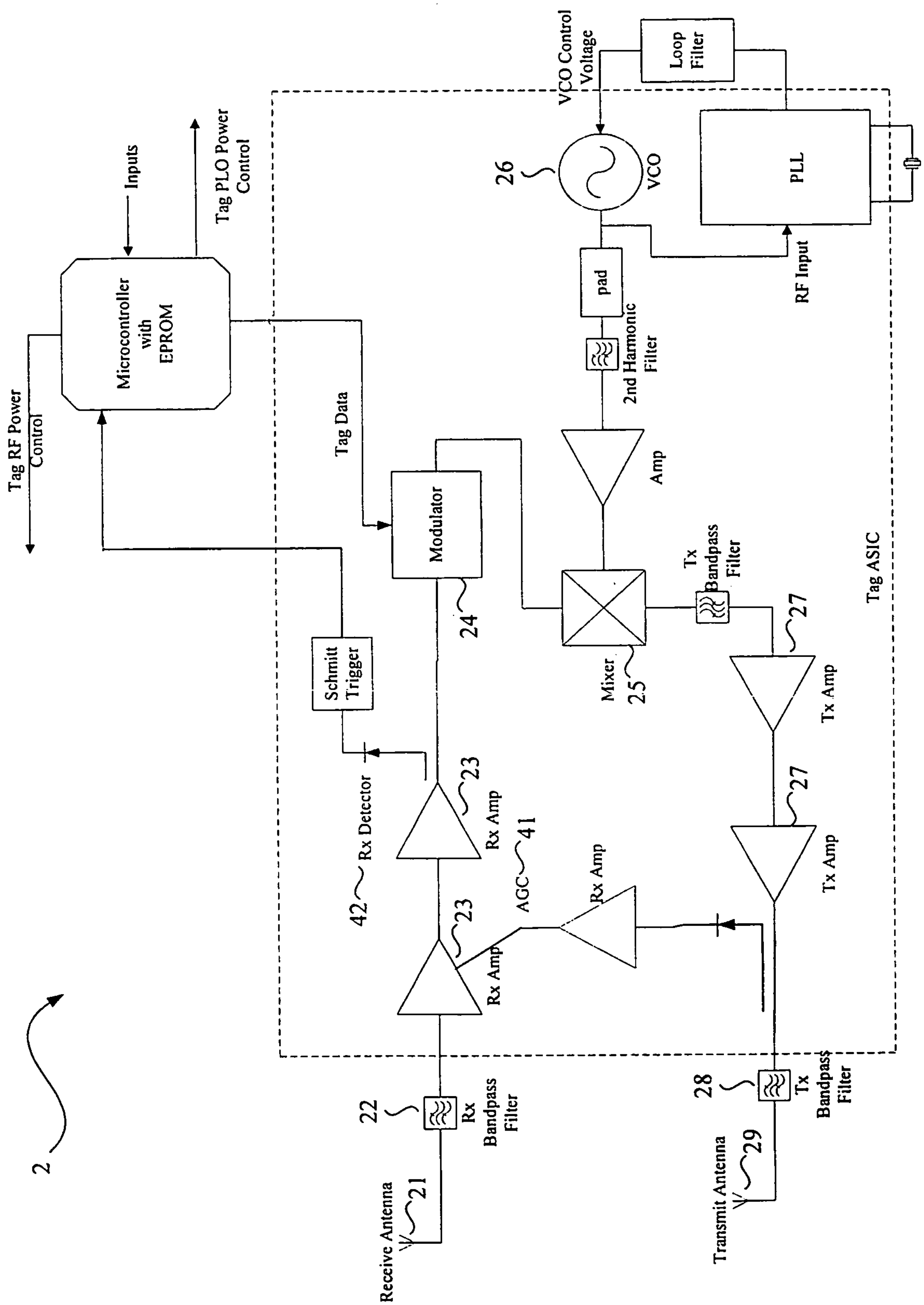
2
Tag RF Power Control
Microcontroller with EPROM
Inputs
Tag PLO Power Control
Tag Data
Modulator
24
Schmitt Trigger
Rx Detector
42
23
Rx Amp
41
AGC
Rx Amp
23
Rx Amp
22
Rx Bandpass Filter
Receive Antenna
21
VCO Control Voltage
Loop Filter
26
VCO
PLL
RF Input
pad
2nd Harmonic Filter
Amp
Mixer
25
Tx Bandpass Filter
27
Tx Amp
27
Tx Amp
Tag ASIC
28
Tx Bandpass Filter
Transmit Antenna
29

Fig. 4